PRESCRIBED FIRE IMPACTS ON RECREATIONAL WILDLANDS:

A STATUS REVIEW AND ASSESSMENT OF RESEARCH NEEDS

#11

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Eisenhower Consortium for
Western Environmental Forestry Research

This report was approved and financially supported by the Eisenhower Consortium for Western Environmental Forestry Research. Member institutions are Arizona State University, Colorado State University, New Mexico State University, Northern Arizona University, Texas Tech University, University of Arizona, University of Colorado, University of New Mexico, University of Wyoming, and the Rocky Mountain Forest and Range Experiment Station, Forest Service, USDA.

STA/STA

Eisenhower Consortium Bulletin 11

February 1982

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PREFACE

The purpose of this paper is to provide an assessment of research needs for fire effects on recreational wildlands on behalf of the Eisenhower Consortium for Western Environmental Forestry Research. The Consortium will use our report to define and program future research efforts. We do not intend to present an all-inclusive literature review and assessment.

The Eisenhower Consortium was established in 1972 to expand the research capabilities of the U.S. Forest Service and the nine Consortium universities: Arizona and Arizona State, Colorado and Colorado State, New Mexico and New Mexico State, Northern Arizona, Texas Tech, and Wyoming. Research efforts to date have emphasized the effects of recreation or recreation management activities on the natural environment or the effects of environmental conditions on the potential for recreation.

In general, research efforts have concentrated on the Rocky Mountains and adjacent High Plains, although findings may be applicable throughout western recreational wildlands. Lewis (1980) provides a summary of previous work conducted under the auspices of the Eisenhower Consortium.

The work completed on this review and assessment of research needs was made possible through Agreement No. 53-82FT-0-114 with the Eisenhower Consortium for Western Environmental Forestry Research.

ABSTRACT

The existing literature on wildland fire is assessed in terms of both the biological and social impacts of prescription fire on recreational wildlands. Gaps in the literature are noted and future areas of needed research are suggested, with particular emphasis on the Rocky Mountains and adjacent High Plains.

Key Words: prescription fire, fire behavior, fire effects, recreational wildlands

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INTRODUCTION

From the beginning of organized forestry, fire has been recognized as an agent of change in forest ecosystems. The need for systematic protection of the multiple resources supported on the nation's wildlands has been acknowledged since the late 19th Century. Mandates for fire protection initially established by the Organic Act in 1897 were significantly strengthened through subsequent legislation, e.g. the Fighting Forest Fires Supplemental Fund of 1908 (31 USC 534), the 1911 Weeks Act (36 Stat. 961), the Clarke McNary Act of 1924 (43 Stat. 653). Such legislation helped develop the nation's fire management policy which, until recently, had aimed at a near total exclusion of fire from wildland ecosystems.

The intentional use of fire when applied under carefully prescribed environmental conditions is now recognized as a viable management strategy that must be considered as one alternative to a policy of complete fire exclusion. In recognition of the historic natural role of fire in certain areas, land managers and scientists are changing their attitudes toward the desirability and likelihood of achieving total elimination of fire from all wildland ecosystems. These changes in attitudes are based on a growing body of scientific research which documents the role of fire in wildland ecosystems. Additionally, the Multiple-Use-Sustained-Yield Act of 1964 (P.L. 86-517), the Wilderness Act of 1964 (P.L. 88-577), the National Environmental Policy Act of 1969 (P.L. 91-190), the 1974 Forest and Rangeland Renewable Resources Policy Act (P.L. 93-378), the National Forest Management Act (P.L. 94-588), and the 1978 Revised Fire Policy of the U.S. Forest Service have provided the administrative impetus for the implementation of the changing attitudes toward fire on public lands.

Two classes of fire are of relevance to this report: prescribed fires and wildfires. A prescribed fire is confined to a predetermined area and burns under conditions specified in advance to accomplish certain objectives (Society of American Foresters 1980). Typical prescription fire objectives include fuel hazard reduction, range and wildlife habitat improvement, seedbed and site preparation, modification of timing and amount of water yields, and manipulation of plant species composition. In contrast, wildfires burn out of control, exceed prescription, and are usually considered destructive. Prescriptions may also be specified for so-called "management fires" allowed to burn under policy guidelines of the U.S. National Park Service and Forest Service. These fires are allowed to burn in order to fulfill land management objectives, although ignition occurrence and pattern are generally unregulated.

PURPOSE

In recent years, wildland fire research has focused on fire history, fire ecology, fuel dynamics, fire meteorology, fire behavior, and fire management activities, including suppression and use of fires. Large amounts of literature are available in all these subject areas, but the need still exists to interpret the research results for purposes of examining prescribed fire impacts on recreational wildlands. This gap exists in spite of assertions (e.g. Connaughton 1972) that fire has a greater direct impact on recreation than on any other non-timber use of the forest.

The goals of this paper are: 1) to review the existing knowledge regarding the use of prescribed fire on wildlands utilized for recreation purposes; and 2) to assess gaps in knowledge that might be addressed in developing future prescription fire research priorities. These priorities should also be of interest to research planners outside the Eisenhower Consortium geographic sphere of interest (see Preface).

APPROACH

Our approach views all wildlands as presenting users with a spectrum of recreation experience opportunities, as outlined by Wagar (1966), Brown et al. (1978), and Clark and Stankey (1979). These authors suggest that wildland recreation opportunities can be defined in terms of both physical and psychological factors affecting users. Thus, we have chosen to analyze wildland fire in terms of the resultant physical changes in an ecosystem, as well as the individual and societal responses to these changes.

Many studies have focused on the physical, biological, and chemical changes resulting from both wild and prescribed fires. Our review and assessment begins with this large body of information, particularly with respect to wild and prescribed fire effects on vegetation, wildlife, soils and water, and air. We then analyze what is known about the integration of fire behavior and fire effects into prescription fire management and planning considerations. We conclude with a discussion of prescription fire impacts on both individual and societal perceptions of recreational wildlands.

LITERATURE PERSPECTIVE

Traditionally, studies of fire effects on wildlands have focused on the physical, biological, and chemical impacts on the various ecosystem components, such as flora, wildlife, soils, air quality, water, and fuels. A related body of information has focused attention on the assessment of historic fire occurrences and effects by vegetation or physiographic type. A national fire effects workshop was held April 10-14, 1978 by the USDA Forest Service in order to summarize existing fire effects research and to prioritize future efforts. The following research review highlights material from the workshop, as well as complementary studies not included in the workshop reviews.

Where appropriate, and in the interest of brevity, summaries from the workshop or similar compendia will be cited in their entirety. Further, a complete listing of all available literature and detailed discussion of all fire

effects are beyond the scope of this review. We have chosen to highlight those studies in each subject area that are most current and noteworthy in terms of contribution to the overall state of knowledge.

THE EFFECTS OF FIRE ON VEGETATION

The Role of Fire by Major Ecosystem Types

Although the literature on the effects of fire on vegetation is by far the largest, it is also the most diverse and hence the least cohesive. The most recent summary article is the Forest Service's state of the art review on the effects of fire on flora (Lotan et al. 1981). This report updates two notable summaries published earlier: 1) the issue of *Quaternary Research* entitled: "The Ecological Role of Fire in Natural Conifer Forests of Western and Northern America" (Wright and Heinselman 1973); and 2) the book entitled: *Fire and Ecosystems* (Kozlowski and Ahlgren 1974).

Based on Kuchler's (1964) major vegetation types, Lotan et al. (1981) provide the following general information:

- (a) a description of each vegetation type, including the major species;
- (b) the geographic range of the type (with maps);
- (c) a description of the climate associated with each type:
- (d) the autecology and synecology of the species present (where possible);
- (e) a description of the fire characteristics, including frequency, size and intensity, associated with each type;
- (f) a description of the fire effects; and
- (g) a discussion of management implications and research needs.

Table 1 outlines the vegetation types that they included in their report. Selected references not included in Lotan's et al. (1981) report are added parenthetically by vegetation type. For example, Volland and Dell (1981) describe the fire effects on coniferous and non-forest flora of the Pacific Northwest.

Additionally, the proceedings of the conference entitled "Fire Regimes and Ecosystem Properties" (Mooney et al. 1981) incorporate several papers that examine the relationship between the fire regime (e.g. frequency and intensity) and the characteristics (e.g. distribution and structure) of the ecosystem. With an intended emphasis on North America, and based to some extent on the available literature, the following ecological regions were discussed: northern ecosystems (Heinselman 1981), western forests and scrublands (Kilgore 1981), grasslands (Kucera 1981), southeastern ecosystems (Christensen 1981), and tropical ecosystems (Mueller-Dombois 1981). In each paper the following four questions were addressed:

1. How have fire regimes changed historically and what future changes are expected?

Table 1. Outline of vegetation types discussed in "Effects of Fire on Flora" (Lotan et al. 1981) with selected additional references (in parentheses) not included in their report

North Pacific Maritime Forests	
Sitka Spruce-Western Hemlock Forest	(Kilgore 1981, Volland and Dell 1981)
Western Hemlock-Douglas-fir Forest	(Kilgore 1981, Volland and Dell 1981)
Pacific Silver Fir-Douglas-fir Forest	
Redwood-Douglas-fir Forest	(Viers 1980, Kilgore 1981)
Forests of the Rocky Mountain West	
Ponderosa Pine Forest	(Kilgore 1981, Campbell et al. 1977, Ffolliott et al. 1977)
Douglas-fir Forest	(Kilgore 1981)
Spruce-Fir Forest	(Kilgore 1981, Heinselman 1981)
Inland Maritime Forest	(Kilgore 1981)
Sierra Coniferous Forests	(Kilgore 1981)
Northern Boreal Forests of Alaska	(Heinselman 1981)
Southern Pine Forests	
Oak Hickory-Pine Forest	(Christensen 1981)
Southern Mixed Forest	(Christensen 1981)
Pocosin Forest	(Christensen 1981)
Sand Pine Scrub	(Christensen 1981)
Subtropical Pine Forest	(Wade et al. 1980)
Northern Coniferous Forests	
Great Lakes Spruce-fir Forest	(Heinselman 1981)
Great Lakes Pine Forest	(Heinselman 1981)
Northeastern Spruce-Fir Forest	(Heinselman 1981)
Conifer Bog	
Deciduous Forests	
Eastern Deciduous Forest	
Northern Hardwood Types	
Seral Stage of Northern Hardwoods	
Mixed Mesophytic Forest	
Elm-Ash Forest	
Oak-Hickory Forest	
Appalachian Oak Forest	
Southern Bottomland Forests	(Christensen 1981)
Woodlands and Chaparral	
Pinyon-Juniper Woodlands	(Kilgore 1981)
Western Oak Woodlands	(Pase and Lindenmuth 1971)
Sclerophyllous Hardwoods	(Kilgore 1981)
Nonforest Areas	
Desert	(Rogers and Steele 1980)
Prairie Grasslands	
Mixed Prairie	(Kucera 1981)
Central Great Plains	(Kucera 1981)
Northern Great Plains	(Kucera 1981)
Sagebrush-Grasslands	(Kilgore 1981)

2. How do different fire regimes affect the distribution of vegetation types?
3. How have different fire regimes affected the development of such features of vegetation structure within those types as species composition, horizontal arrangement of individuals, or pattern, and the vertical arrangement, or stratification, of life-forms, growth-forms, and species?
4. How do variations in vegetation structure affect fire regimes? (Bonnicksen and Christensen 1981).

These papers represent a promising and much-needed perspective, but Bonnicksen and Christensen's (1981) introduction serves notice that these are difficult questions and, in some cases, the literature is too sparse or inconclusive to provide adequate grounds for satisfactory answers.

Finally, Wright and Bailey's (in press) book entitled *Fire Ecology: United States and Southern Canada* should add to the fire ecology literature. It is scheduled for release in February, 1982.

The remainder of this section deals specifically with forest ecosystems, grassland and rangeland ecosystems, and shrubland and woodland ecosystems. Because of the large volume of literature (especially concerning forest ecosystems), it is not feasible to elaborate on specific fire effects. Interested readers should refer to the cited works for additional details.

Forest Ecosystems

Specific summaries deal with individual species, forest types, or management units. Wright (1978) presents a state of the art review of the effects of fire on ponderosa pine *(Pinus ponderosa)* forests. He discusses the distribution, climate, soils, and general post-fire successional pattern of the ponderosa pine type. The vegetation and fire effects are presented for six specific habitat types: two representing climax ponderosa pine communities and four representing seral ponderosa pine types. He closes with a discussion of management implications and research needs, indicating that although fire has the potential to be a safe and economical management tool, specific prescription guidelines need to be developed for a wide variety of weather conditions, stand characteristics, and management objectives.

A rather complete overview of the effects of fire on the northern Canadian boreal forest is presented by Kelsall et al. (1977). They describe the climate, topography, soils and vegetation of the boreal forest, the history of fire, and the effects of fire on vegetation, wildlife, soils and hydrology. In their summary, they state that the effects of fire on the boreal forest cannot be classified as either totally positive or negative. The precise effects depend on the values that may be destroyed or created.

Davis et al. (1980) present the available information on fire as an ecological factor for forest habitat types occurring on the Lolo National Forest. The habitat types are combined into ten fire groups based primarily on fire's role in forest succession. For each group, information is presented on the relationship of major tree species to fire, forest fuels, the natural role of fire, fire and plant succession, and related fire management considerations.

Finally, several studies deal specifically with modeling and predicting post-fire plant succession. In contrast with traditional Clementsian theory, evidence suggests that the pattern of post-fire succession for an individual ecosystem is a function of species characteristics, fire periodicity, and fire intensity (Noble and Slatyer 1977, Catelino et al. 1979). Lyon and Stickney (1976) indicate that composition of the preburn ecosystem is an important determinant of post-fire succession. Kessell and Fischer (1981) present techniques for describing and predicting fire-related plant succession. The methods are specifically designed to help managers utilize their own data to integrate fire management considerations into the land management planning process, and as a result, several simplifying assumptions are made. Kessell and Fischer (1981) conclude that there are a number of difficult and basically unanswered questions about post-fire plant succession, including prediction of vegetation mortality as a function of differential fire behavior (e.g. fire intensity), the validity of extrapolating data and results from one forest to another, and the utility of the models themselves.

Noble (1981) presents a thought-provoking review of major successional theories, describing a shift in thinking from an emphasis on community processes (e.g. competition) to species' properties (e.g. r and K strategies). In areas subjected to recurrent fire, he suggests that the period of regeneration is of major importance in determining community composition. Although successional theories are fraught with exceptions and complications, Noble (1981) contends that special emphasis on this regeneration niche should provide the basic data needed to understand vegetation dynamics.

Grassland and Rangeland Ecosystems

The recent work by Wright and Bailey (1980) provides an up-to-date review of fire ecology and prescribed burning in the Great Plains. Their paper contains basic ecological information, vegetative descriptions and fire effects data for the shortgrass, mixed grass, and tallgrass prairies of the southern, central, and northern Great Plains. Species-specific fire effects data have been tabulated and prescription guides are provided for all vegetation types where data are available. According to their review, the major benefits of prescribed burning in grasslands are to control undesirable shrubs and trees, burn dead debris, increase herbage yields, increase utilization of coarse grasses, increase availability of forage, improve wildlife habitat, and to control cool season species where warm season grasses are dominant. Detrimental fire effects are generally associated with its misapplication (e.g. burning during an inappropriate season, or on steep slopes).

Wright (1980) presents a similar treatment for the semidesert grass-shrub type in southeastern Arizona,

southern New Mexico, and southwestern Texas. He notes that grasslands in this type have gradually given way to higher densities of shrubs in the past 75 years, and indicates that the role fire plays, in conjunction with drought, competition, and herbivory, is not well understood. Likewise, Wright et al. (1979) review the role of fire in sagebrush-grass plant communities of the western United States. They indicate that responses of most shrubs and herbs to fire are known, but more information is needed on species' responses to variations in fire intensity, season of burn, plant size, and soil moisture.

Additionally, Wade et al. (1980) synthesize available information regarding fire effects on the major ecosystems of southern Florida. They discuss the historical effects and describe the responses of selected plant communities to changes in frequency and intensity of fire under current conditions. Their intent is to provide a compendium of fire information to aid resource managers and policymakers in predicting the consequences of fire management decisions.

In earlier works, Vogl (1974) and Daubenmire (1968) present more generalized approaches to fire ecology in grasslands in that their reviews are not restricted to specific plant communities or geographical areas. Vogl discusses the general role of fire in grasslands, the physical character of grassland fires, the effects on productivity, species composition, and successional change. He also treats the use of fire in grassland management. Similarly, Daubenmire presents a thorough treatment of the character of grassland fires and the effects of fire on the environment, on individual plants, and on plant communities.

Shrubland and Woodland Ecosystems

As cited in the grasslands section, the works by Wright (1980) and Wright et al. (1979) are up-to-date summary articles on the role and use of fire in semidesert grass-shrub, sagebrush-grass, and pinyon-juniper types. There exists no general summary article on fire in shrublands or woodlands, although Fischer (1980a) indexes several papers at the Tall Timbers Fire Ecology Conferences dealing specifically with these types.

The chaparral vegetation types deserve special mention in that catastrophic fires are often associated with these plant communities. Biswell's (1974) summary includes a discussion of the kinds of chaparral, occurrence of fire in chaparral, chaparral adaptations to fire, and post-fire plant successions. The Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems (Mooney and Conrad 1977) includes papers dealing with the role of fire in chaparral ecosystems of Australia, California, Chile, France, Greece, Israel, Italy, North Africa (i.e. Morocco, Algeria, Tunisia, Libya, and Egypt), South Africa, and Spain. The proceedings of the Symposium on the Dynamics and Management of Mediterranean-type Ecosystems (Conrad and Oechel, in press) should augment previous studies of fire and vegetation management in chaparral wildlands.

Literature Assessment

Few generalizations are possible regarding the role of fire in major western and northern American ecosystem types, in spite of the large volume of available literature. Existing information is generally non-quantitative and suffers from a lack of experimental control over independent variables. Linkages are poorly documented between differential fire behavior (e.g. variations in fire intensity and duration) and resultant fire effects. Study results are generally incomparable, even for the same vegetation type, because of the difficulty in discerning the sources of variability. Many studies ostensibly report fire effects, even though such studies may focus instead on ex-post facto differences in unburned versus burned areas. Such comparisons may be invalid due to innate site differences.

Fire History

Quantification of historic fire frequencies aids in the understanding of the ecological role of fire and provides useful prescription fire management guidelines. Methods used to determine fire frequency have included: examination of historical records, journal accounts, and fire occurrence records; analysis of lake sediment for pollen and charcoal; analysis of increment cores or logging stumps; dating of fire scar samples from standing trees; and inferences from vegetation age analysis.

The major published literature and significant unpublished reports on forest and rangeland fire history are contained in Alexander's (1979) bibliography. Although the emphasis is on North American references, selected citations from other continents are included. A total of 307 references dating back to 1900 are conveniently indexed by subject area and geographical area. Additionally, Arno (1980) has summarized forest fire history in the northern Rocky Mountains.

The Proceedings of the Fire History Workshop (Stokes and Dieterich 1980) contain several papers that collectively discuss sampling procedures, research methodologies, data interpretation, and the relationship of dendrochronology procedures to fire history interpretations. In his workshop summary, Mutch (1980) lists the following factors that limit the interpretation and application of fire history information:

1. Flammable exotic species tend to obscure "natural" fire frequencies;
2. Changing cultural activities over time confound the "natural" fire history record (e.g. burning by aboriginals, miners, trappers, settlers);
3. Climatic changes occur;
4. Grazing patterns change;
5. Fire scars represent a conservative history (fires must be intense enough to scar the cambium tissue);
6. Stratification of data is sometimes difficult;

7. It is difficult to date events in certain ecosystems (e.g. fires in the Sonaran Desert leave few direct signs);
8. Fire chronologies that are not cross-dated may impair the accuracy and amount of information collected; and
9. The importance of fire history information to fire suppression, prescribed fire and land management planning programs is not fully recognized.

Other limitations also confound the analysis and interpretation of fire scar data. Differences in sampling intensity and study area size hinder comparisons of fire history between stands. Additionally, sample sizes generally decrease as time before present increases due to natural attrition of older trees. This creates interpretation problems since "natural" fire frequencies should be best represented by the oldest records.

Imprecise and misused terms add to the confusion embodied in this literature. The Fire History Workshop committee report on terminology (Romme 1980) represents a major step in overcoming this shortcoming. Although the report should not be considered a fire history glossary, it contains definitions of preferred terms (and synonyms) that caused the greatest confusion or were in the greatest need of clarification at the Workshop.

Finally, the data generated from fire scar analysis (i.e. a measure of fire frequency) represent only one element of the fire regime that characterizes a study area. Use of fire scars for determining other fire regime elements, including fire intensity, fire size, and season of occurrence, is currently not feasible. These shortcomings collectively limit the potential of fire history studies to provide ecologically meaningful guidelines for fire management planning.

Literature Assessment

Fire history studies are often conducted to provide guidelines for fire management planning efforts. Evaluations of fire suppression, prescription fire, and land management alternatives are facilitated by the information obtained about the natural history of a stand or planning unit. Even so studies suffer from inherent data limitations and differ with respect to terminology, analytical procedure, and data interpretation. These shortcomings restrict the usefulness of fire history studies for their intended purposes and also limit the inferences that can be drawn from inter-stand comparisons.

Fire and Individual Plant Response

In this section, our review focuses on two primary plant responses: mortality and growth reduction. It should be noted that the literature in this area deals mainly with tree species.

To date, Hare's (1961) comprehensive review of the heat effects on plants is the most noteworthy single publication in this field. He examines factors outside the plant that control heat injury (e.g. temperature and its duration) as well as internal variables that also are influential (e.g. transpiration, thermal emissivity). He also discusses species differences (e.g. growth form, sprouting ability, bark thickness) and the physiological factors in heat resistance (e.g. succulence, hardening).

Additional research has focused on the relationship between bark characteristics and fire temperatures outside the tree to the occurrence of lethal temperatures in the cambial region. Spalt and Reifsnyder (1962) provide a comprehensive review of this subject, and Kayll (1966) describes a technique developed for studying heat transfer to the cambium.

The degree of crown scorching has been related to fire-caused mortality. The works of Herman (1954), Lynch (1959), Storey and Merkel (1960), Wagener (1961), Methven (1971), Van Wagner (1973), Dieterich (1979), and Bevins (1980) are notable examples from this literature. In addition to foliage kill, Wagener (1961) suggests that bud and twig kill, and bark and cambium kill must be considered in judging whether a tree is likely to live after fire injury. Also the season of burn, age, growth rate, site, and subsequent bark beetle activity all regulate the survival potential of an individual tree (Wagener 1961). Dieterich (1979) concludes that the factors that influence the ability of individual ponderosa pine trees to survive the effects of fire include: 1) percent of crown scorch and/or crown consumption; 2) extent of cambium damage; 3) season in which the fire occurs; 4) presence of insects; and 5) rainfall during the growing season following the fire.

Individual tree growth reduction can be significant when a sufficient loss of photosynthetic surface results from crown scorching. Morris and Mowat (1958) and Langdon (1971) report that height growth appears to be more susceptible to reduction than diameter growth in fire-damaged trees. On the other hand, results of a study assessing ponderosa pine crown scorch indicate that fascicle growth of scorched trees is significantly greater than control tree fascicle growth (Wyant 1981).

Literature Assessment

Existing studies on fire and individual plant response have focused on the analysis of fire effects on trees, with scant attention to studies of heat effects on individual shrub or grass plants. Because of the many variables that influence the survival potential of individual trees, the capability to accurately predict tree mortality following fire is not fully developed. Additionally the effects of season of burning on fire behavior and resultant plant sensitivity have not been adequately explored. These weaknesses are confounded since fire may induce susceptibility to other mortality agents (e.g. insects, disease).

Fire and Plant Adaptation

According to Gill (1981), plant traits adaptive to fire are all those traits contributing to the successful completion of the life cycle of a species in a fire-prone environment. Some traits have been emphasized in the literature because of their obvious survival or reproductive value. The selective mechanisms involved are not well understood, yet ecologists generally accept the concept that fires act as a selective force. In relation to cone serotiny in lodgepole pine *(Pinus contorta)*, Perry and Lotan (1979) formulated a hypothetical model of fire selection that indicates that fire frequency can influence the alteration of gene frequency.

Several authors have proposed classifications of adaptive traits for plants subject to fire (Horton and Kraebel 1955, Le Houerou 1974, Naveh 1975, Gill 1977, 1981). Gill (1981) distinguishes four major adaptive trait categories (as outlined below) and provides specific examples:

1. Bud protection and plant survival
    a. bark thickness and bud protection
    b. subterranean protection of buds
    c. bud protection by leaf bases
    d. bud protection and resprouting after fire
2. Fire-stimulated flowering
3. Seed storage on the plant and fire-stimulated dehiscence
4. Storage of seed in soil and fire-stimulated germination.

Gill's (1981) system is convenient but may not readily accommodate all fire adaptations [e.g. the suggestion that heightened flammability is a trait of fire-adapted plants (Mount 1964, Mutch 1970)].

Even though the literature in this area tends to attribute fire as the selective force for the evolution of these traits, currently this inclination has to be considered speculative. As Gill (1981) points out, the many traits enhancing survival during fires may also enhance survival during stress from other environmental factors. For example, resprouting may also be adaptive to browsing, insects or disease. Similarly, Linhart (1978) suggests that thick-scaled cones provide seed protection from high temperatures of fire and also may deter attacks from squirrels. Therefore, it is conceivable that either of these traits may not have arisen directly in response to selection by fire. Likewise, traits considered adaptive to fire may in fact be preadaptations to fire rather than a consequence of fire selection.

Other: Fire and Pathogens

Although the effects of fire on plant diseases have received relatively little attention, most of the available literature relates to the use of fire for control or reduction of the severity of the pathogen. In reviewing the literature concerning fire-disease interactions, Fellin (1980) highlights the three most noteworthy interactions: 1) brown-spot needle blight *(Scirrhia acicola)* of longleaf pine *(Pinus palustris)*, representing a classic example of the use of fire to control disease; 2) dwarf mistletoe *(Arceothobium* spp.); and 3) root pathogens, primarily *Fomes annosus*. Lotan et al. (1981) add fusiform rust *(Cronartium quercuum)*, a serious disease of southern pines, to the above list of major fire-disease interactions.

Parmeter (1977) states that there is little hard evidence that fire significantly affects the impact of diseases in plant communities exposed to fire or established after fires. He summarizes the known or possible beneficial and harmful effects of fire [as outlined by Lotan et al. (1981)] below:

A. Beneficial Effects
    1. Sanitizes and eradicates disease by lethal fire temperatures
    2. Destruction of inoculum
    3. Destroys insect vectors of disease
    4. Alters physical or chemical properties of soil or populations of soil- and root-inhabiting microorganisms
B. Harmful Effects
    1. Stimulates spore germination, fungus growth and fruiting
    2. Intense heat causes fire scars, often resulting in butt rot
    3. Fire or long-term fire suppression may lead to development of pure stands often more susceptible to pathogens
    4. Fire or fire exclusion may lead to build-up of alternate hosts of disease; fire may increase succulence of host tissue and increase susceptibility to disease
    5. Interferes with evolution of resistance in plants
    6. Smoke injury to host plant, creating infection courts.

Subsequent to the above summary, Froelich et al. (1978) studied the effects of prescribed burning on the severity of annosus root rot in slash *(Pinus elliotii* var *elliottii)* and loblolly *(P. taeda)* pines distributed through the Southern Coastal Plains. They found that mortality and total infection (dead plus living infected material) were significantly reduced by burning treatments and the greatest beneficial effects were found where disease was most serious. The mechanisms of control provided by the prescribed fire were not clear.

The Effect of Fire on Vegetation: Research Needs

Fire effects on vegetation are not easily generalized. The biotic and abiotic interactions that influence observable post-fire vegetation are complex and not fully understood. Additional difficulties have been created by the manner in which fire effects on vegetation have been studied and reported. Until recently, many studies have overlooked the impacts of inherent variability in the profile of fire behavior, both above and below the ground surface and over time. In addition, scant attention has been given to accounting for the impact of independent influences (e.g. post-fire climatic conditions) on resultant vegetation

composition and structure. Fire has often been studied as a uniform "treatment" whose effects can be ascertained by comparisons with unburned "controls" or by mere inspection of burned areas (without consideration of conditions existing before, during, and after ignition). Finally, many studies are short-term and thus inadequate for assessing fire's role over time.

Consequently, information about fire effects on vegetation is disjoint and laden with oversimplification. Though many studies of fire effects on vegetation have been conducted, relatively few can be replicated to verify previous findings. Further, there is a need for basic understanding that can be translated into guidelines for resource management.

Based on our assessment of previous studies, the highest priority for future research should be given to studies of: 1) fire's role in ecosystem dynamics; 2) individual plant responses to fire; and 3) fire history. Our rationale is that basic understanding in these subject areas should necessarily precede peripheral scientific inquiries.

(1) The Role of Fire in Ecosystem Dynamics

Although general successional pathways are described for most vegetation types, specific projections of successional change over time have not been adequately documented. We know even less about how variations in fire behavior, timing and season of burning, and frequency of burning affect these successional trends. Most of the research has concentrated on major tree species; we therefore have scant knowledge of the associated changes in herbaceous and shrub species.

In order to establish baseline information on vegetation succession and to quantify long-term fire effects on successional trends resulting from differential levels of fire activity (e.g. fire frequency, recurrence, timing and seasonality), the following specific research needs are emphasized:

- (a) Determination of post-fire succession sequences in the major fire-adapted ecosystems of the southern and central Rocky Mountains (e.g. oak *(Quercus gambelii)* woodlands and shrublands, ponderosa pine forests, mixed conifer forests, aspen *(Populus tremuloides)* woodlands, spruce-fir *(Picea engelmannii-Abies lasiocarpa)* forests, shortgrass prairie, sage-bitterbrush *(Artemisia tridentata-Purshia tridentata)* shrubfields, alpine meadows, and riparian zones, including herbaceous and shrub species.
- (b) Quantification of the effects of differential fire behavior and recurrent fire on these successional sequences.
- (c) Development of predictive models for plant succession that incorporate variations in fire frequency and intensity for fire-adapted ecosystems.

(2) Individual Plant Response to Fire: Tree Mortality

In order to successfully prescribe fire, we must develop the capability to predict tree mortality. Mortality can be caused directly from the heat of a fire by crown scorch, cambial kill, and/or root kill. In addition, we do not have the capability to predict the influence of subsequent indirect mortality agents (e.g. insects, disease). The effects of season on plant sensitivity to prescription fire are also poorly understood. Van Wagner's (1973) model for predicting crown scorch and Bevin's (1980) model for estimating survival of fire-scarred Douglas-fir *(Pseudotsuga menziesii)* trees should be tested for use with local tree species and subjected to variation in fire behavior characteristics. Development of models that characterize the heat pulse to the cambial and root regions should also be encouraged.

(3) Fire History

Assuming that the major terrestrial ecosystems of the Rocky Mountain region have evolved in the presence of recurrent fire, knowledge of historical fire frequencies and associated intensities can form the ecological foundation for wise fire management planning. To date, quantification of pre-suppression fire history is lacking for most vegetation types, especially in the central Rockies. We therefore place a high priority on the acquisition of these data according to a standard methodological format. Because of the management implications of this information, future studies should be sensitive to the limitations associated with fire history documentation. Finally, although standard sampling methods have been developed, there is a need to standardize techniques for analysis and interpretation of fire history data.

THE EFFECTS OF FIRE ON WILDLIFE

Most of the literature on fire effects deals with plants and soils, and very little work deals directly with the effects of fire on fauna. As Bendell (1974) points out in his summary paper, it is difficult to pinpoint cause and effect relationships between the action of fire and response of animals. He cautions that few studies are quantitative, have adequate controls, or have been carried on long enough to assess the effect of a particular fire on wildlife.

The largest volume of research in this area has focused on the direct and indirect impacts of fire on fauna (our coverage is restricted to wildlife species, although there is a literature dealing with fire effects and domestic species). Bendell's (1974) article dealing with birds and mammals is considered a primary reference source. Lyon et al. (1978) updated Bendell's summary and added literature pertaining to invertebrates and stream fauna. Their work synthesizes a total of 450 citations and represents the latest state of the knowledge review.

Direct Effects

Lyon et al. (1978) report a general consensus among authors that fires are responsible for small or insignificant levels of direct vertebrate mortality, although faunal mobility, fire size, and seasonality influence animal survival. This opinion affirms the findings of Lillywhite (1977)

and Wirtz (1977) regarding fire's negligible direct effect on chaparral wildlife, although both authors note possible shifts in species composition and diversity. In assessing the effects of logging and fire on small mammals in northwestern Montana, Halvorson (1981) suggests that since most rodents nest underground, sometimes several feet below the surface, and since soil is an excellent insulator, large numbers of rodents survive fire in place. Although measured surface soil temperatures reached 500° F for one burn, subsurface temperatures at 2 inches were 118° F, several degrees below the reported lethal level. Generally suffocation, not high temperatures, is the probable cause of small mammal mortality (Lawrence 1966). Invertebrates, especially soil fauna, that lay eggs or have immature forms in the duff and litter layers are susceptible to fire, whereas surface insects that have the ability to fly, escape down tunnels, or are afforded protection by bark, usually survive.

Indirect Effects

Short-term

Lyon et al. (1978) suggest that terrestrial fauna are confronted with a sudden and drastic modification of habitat structure and microclimate, and, depending on the species, the effects can be either positive or negative. For example, Halvorson (1981) reported only deer mice two weeks after an intense burn whereas, on a "cool" burn, deer mice and chipmunks were found. The cooler burn provided a more diversified environment with favorable cover and food sources, undoubtedly favored by chipmunks. For stream fauna the most important detrimental effects are related to sediment input (e.g. smothering of eggs or preventing emergence of fry) and loss of streamside vegetation (e.g. resultant increases in stream temperatures).

Long-term

Major modifications of habitat are commonly the result of fire occurrence. Early successional plant species generally increase and, as a result, faunal species associated with seral communities increase (e.g. larger game animals such as moose, deer, grouse). Late successional species (e.g. caribou, wolverine, marten) may temporarily be displaced or eliminated (Lyon et al. 1978). Scotter's (1977) description of caribou and moose response to wildfire-induced habitat changes in northern Canada and Basile's (1979) work on elk utilization of aspen clones treated with late summer prescription fire support these conclusions.

Although less is known about smaller, non-game species, generally post-burn small mammal and bird populations remain about the same in both density and trend as pre-burn populations (Bendell 1974). Klebenow and Beall's (1978) summary paper tends to substantiate these generalities. However Ream's (1981) overview of fire effects on small mammals suggests that the long-term response of many species is increased numbers, primarily due to increased growth of herbaceous and seed-producing plants.

Gruell (1980) notes changes in wildlife habitat associated with reductions in fire frequency since 1900 for conifer, aspen and cottonwood (*Populus* spp.), willow (*Salix* spp.), shrub, and grass ecosystems in Bridger-Teton National Forest, Wyoming. He concludes that the area has experienced succession to conifers and sagebrush accompanied by buildup of heavy fuels, loss of understory plants, and a reduction in carrying capacity for wildlife.

Other: Insects

Fischer (1980b) suggests the difficulty of generalizations, but notes that season and crown scorch are important in determining the susceptibility of ponderosa pine forests to pine beetle infestations (*Dendroctonus brevicomis, D. valens*, and *Ips pini*). Force (1981) observed high insect richness and diversity in the first spring following a chaparral fire in southern California, paralleling the associated plant species richness and diversity.

The Effects of Fire on Wildlife: Research Needs

Animal communities exist in dynamic equilibrium with their environment. While fire-induced biotic and abiotic changes may temporarily favor certain faunal species over others, the balance changes continually over time.

One of the major problems in attempting to generalize about the effects of fire on fauna is the lack of information on the direct and indirect impacts resulting from fires that differ in behavior (e.g. intensity, duration, frequency, size, and shape). Studies are needed in this subject area, but cannot be conducted by either fire scientists or zoologists alone. An understanding of fire impacts on fauna will require knowledge of faunal species' fire sensitivity and habitat requirements as affected by differential fire regimes. We feel the highest priority for research in this subject area should be attached to interdisciplinary studies that relate faunal habitat changes to variations in fire behavior over time. However, this subject area is generally of lower priority than the study of fire effects on vegetation, especially since vegetation is crucial to the definition of faunal habitat.

THE EFFECTS OF FIRE ON SOIL AND WATER

The most comprehensive review of the literature concerning fire effects on soils is presented by Wells et al. (1979). Their summary indicates that fire destroys organic matter, volatilizes some mineral elements, transforms elements to soluble forms, and alters the physical, chemical and biological properties of soil. Their major conclusion is that fire intensity and the resulting degree of exposure of mineral soil to heat govern the degree of response of all soil properties reviewed. For example, low intensity fires can facilitate nutrient cycling, control plant

pathogens, and enhance productivity whereas intense fires can volatilize essential nutrients, destroy organic matter, induce water repellency, and consequently increase erosion and decrease productivity.

The close interface between fire effects on soils and the resultant impact on hydrologic processes and water resources is given comprehensive coverage by Tiedemann et al. (1979), Swanson (1981), Tiedemann (1981), and Wright (1981). The former publication summarizes onsite and downstream fire effects. Although effects are variable, the following common responses are emphasized:

1. Fire leads to increased overland flow and greater peak and total discharge, providing the transport force for sediment;
2. Erosion responses to burning are a function of degree of elimination of protective cover, steepness of slopes, degree of soil wettability, climatic characteristics, and rapidity of vegetation recovery;
3. The most serious threats to water resources following fire appear to be sedimentation, increased turbidity levels, and mass erosion;
4. Despite lack of documentation, large fires of high intensity appear to have the greatest potential for causing damage to water resources;
5. Although fire results in increased levels of nutrients in overland flow and in soil solution, surface water quality is not significantly impaired; and
6. Although poorly documented, composition or productivity of benthic macroinvertebrates are not adversely affected by water quality changes.

DeByle and Packer (1981), studying the effects of logging and fire on soils and watershed in conifer forests of northwestern Montana, concluded:

1. Burning of broadcast logging debris should not induce significant water repellency;
2. Removal of surface organic horizon, particularly when fires are intense, may result in severe erosion, especially on steep slopes;
3. Mineral soil pH increased and nutrients released by cutting and burning were probably trapped by these fine-textured soils in the rooting zones, not altering site quality; and
4. Increases in runoff and erosion were generally considered acceptable from a management perspective.

In addition to the above summary articles, Zinke (1977), DeBano et al. (1977, 1979a, 1979b), Dunn and DeBano (1977), DeBano and Conrad (1978), and Dunn et al. (1979) have focused on fire effects on physical, chemical, and biological properties of chaparral soils. For example, fire-induced changes in soil and litter characteristics, site productivity, soil nutrients, soil organic matter, cation exchange capacity and pH, soil wettability (specifically see DeBano's (1981) review of this subject), and soil microorganisms are summarized. Boyer and Dell (1980) similarly examine fire effects on soil physical and chemical properties in the Pacific Northwest, while Packer and Williams (1974) assess hydrologic and soil stability factors following prescription fire in the northern Rockies.

The Effects of Fire on Soil and Water: Research Needs

The effects of fire on most soil and water properties depend to a large degree on the intensity of fire. In this regard, the needed research in this area should focus on the quantification of the relationship between fire intensity and the following soil/water properties:

1. soil heating (as it influences soil properties and subterranean plant parts);
2. soil erosion and soil stability, by soil types;
3. nutrient cycling and nutrient availability;
4. overland flow and sediment flow; and
5. aquatic habitat modification.

We believe the highest priority for prescription fire research should be with relationships that can be studied under controlled experimental conditions, in order to quantitatively identify fire effects while minimizing the influence of confounding variables. Isolation of prescription fire effects appears to be most feasible in studies related to the quantification of soil heating (and consequent influence on soil properties and plant parts). Prescription fire research into the other soil/water study topics is needed, but experimental controls necessary to ascertain the effects of fire treatment may be less feasible.

THE EFFECTS OF FIRE ON AIR

Wildland fires inevitably produce smoke due to the incomplete combustion of available fuels. Smoke management is especially important near urban areas because of the visual impacts and potential effects on human health. Fox et al. (1979) indicate the general difficulties of assessing and quantifying visibility impacts, even if obvious. On the other hand, smoke emission products and potential impacts on human health have been extensively studied.

McMahon and Ryan (1976), Sandberg et al. (1979), and Tiedemann (1981) have summarized chemical and physical characteristics of forest fire smoke emissions, including the expected ranges in CO_2, H_2O, CO, particulates, hydrocarbons and other organics, and nitrous and sulfur oxides. These authors agree that particulates pose the principal air pollution problem from wildland fires. The Society of American Foresters (SAF) Task Force on Clean Air Act Regulations (1980) suggests that wildfires account for 70-85 percent of the total particulate production from wild and prescribed fires because of larger acres burned and higher emission yields.

Sandberg et al. (1979) found that emission yields vary up to two orders of magnitude, depending on fuel type and fire behavior. They include useful tables of annual

prescription fire acreages and criteria pollutants emitted, by U.S. geographic region. They also present graphs of wild and prescribed fire particulate production, by region and season (from Ward et al. 1976). The SAF Task Force on Clean Air Act Regulations (1980) use these and other data in support of prescribed burning on forest and rangelands, in spite of the occasional nuisance or hazard of prescribed fire smoke.

Tiedemann (1981) elaborates the off-site consequences of smoke and other combustion products from prescribed fires. He notes that smoke impacts may range from the relatively obvious to the very subtle (e.g. the "brown cloud" vs. effects of light attenuation or emission products on adjacent plant communities).

Fire managers are able to regulate the production and distribution of smoke by specifying conditions within the prescription that favor dispersal from affected areas, including fuel moistures, atmospheric stability, direction of winds aloft, timing of ignition, and firing techniques. Several decision-making guides are currently available. Mathematical models of smoke transport and dispersion from prescribed fires include the modified-Guassian distribution model discussed in Mobley (1976) and Sandberg et al. (1979), and Norum's (1974) multiple regression model relating smoke column height to fire intensity. Vines (1977) presents a model for determining the minimum visual range in smoke downwind of large-scale prescribed burns in Australia, noting that smoke minimally impacts overall air quality, even when mixed with urban air. Furman (1979) describes two computer programs that utilize historical fire weather data bases to estimate probabilities that future burning will fall within smoke dispersal prescriptions.

The Effects of Fire on Air: Research Needs

Assuming that prescription fire will increase in importance nationwide, information on the following subject areas is evidently lacking with regard to fire effects on air:

1. Relationships between quantifiable fire behavior parameters and smoke impacts (including visibility value effects);
2. Site-specific analyses of the potential trade-offs between prescription fire usage and expected wildfire activity in the absence of prescribed burning; and
3. Causal relationships between smoke products and forest pathogens.

These information gaps assume varying degrees of importance for different regions of the nation. For example, emissions from silvicultural burning are of greater current importance in the Pacific Northwest than in the central Rocky Mountains and adjacent High Plains. These differences are related to factors such as dominant land uses, proximity to smoke-sensitive areas, and traditions. Overall, we feel that smoke effects are less of an issue within the Eisenhower Consortium's geographic sphere of interest than other fire effects.

PRESCRIPTION FIRE MANAGEMENT AND PLANNING

The mechanics of writing prescriptions and operational procedures for conducting successful burning operations have been discussed by Beaufait (1962), Riebold (1964), Martin (1978), and Fischer (1978). Fischer (1980a) includes a listing of all papers presented to the Tall Timbers Fire Ecology Conference regarding fire management prescriptions and fire techniques.

The success of any burning operation is in a large part determined by the degree to which planners and managers can anticipate the many contingencies that arise prior, during, and after a prescription fire. Judicious planning requires the integration of prescription fire behavior and effects knowledge into a framework for overall land management planning, including social and economic considerations over time. Egging et al. (1980) present one framework that planners could use to determine whether fire should be used or excluded in meeting management objectives in a given land area.

Estimates of prescription fire behavior are as essential to the planner as the fire boss anticipating on-site resource allocation problems. Both the planner and field manager must utilize available information and expertise to characterize anticipated fire behavior, even if for different reasons. The purpose of this section is to assess the state of knowledge regarding fire behavior characterization, particularly as related to the preparation of prescription fire plans and operational guidelines.

Basic influences of fuels, weather, and topography on fire behavior have been summarized by many authors, including Barrows (1951), Schroeder and Buck (1970), Countryman (1972), and Brown and Davis (1973). Rothermel (1972) integrated important fuel, weather, and topographic influences in his model of fire spread in uniform, homogeneous fuelbeds. His model has been subsequently used in the estimation of fire behavior/fire danger, namely, Albini's (1976) nomograms for estimating fire behavior in the Northern Forest Fire Laboratory's fuel models; the stylized fuel models of the National Fire Danger Rating System (NFDRS) of Deeming et al. (1977); the dynamic fuel models for southern California chaparral (Rothermel and Philpot 1973) and slash hazard appraisal in the Intermountain Region (Albini and Brown 1978). Other uses and tests of the Rothermel spread model are discussed in Andrews (1980). In general, the model's utility for prescribed fire planning and execution is not well-documented. This is not surprising, because the data requirements for successful prescribed burning predictions may be more stringent than for other applications of the Rothermel model (Albini 1976).

Fire managers and researchers have recently recognized the importance of specifying or characterizing prescription fire behavior necessary to achieve particular management objectives/fire effects. Fire intensity, heat per unit area, residence time, and combustion duration are among the fire behavior measurements considered important by

various authors, including Van Wagner and Methven (1978), Rothermel and Deeming (1980), Dell (1980), Brown (unpublished), and Brown and Fischer (unpublished). Guidelines for monitoring fire behavior during prescription fires include Beaufait's (1966) water-can analog for total heat released, Pickford and Sandberg's (1975) motion picture triangulation technique for transitory, but visible fire phenomena, McRae's et al. (1979) measures of frontal fire intensity based on fuel consumption, and Rothermel and Deeming's (1980) derivation of fireline intensity and heat per unit area via ocular flame length estimates and rate-of-spread markers.

The achievement of desired fire behavior is dependent on the degree to which environmental conditions satisfy the prescription specified for the burn. Success is also dependent on the extent to which uncertainties can be reduced in forecasting the weather and resultant influences on fire behavior. Furman (1979) and Bradshaw (1980) present similar approaches for using archived fire weather data to develop probability statements that prescription fire weather parameters will be achieved during discrete time intervals within a burning season. These weather parameters can be linked to anticipated fire behavior and, in turn, to anticipated effects even though these relationships are not well-documented in the literature.

Documentation of fire weather-fire behavior relationships is especially lacking in earlier case histories of prescription fire. Recent recognition of the need to establish bases for prescription comparisons has partially alleviated this information gap, as evidenced by the representative list of studies where authors have cited prescription fire parameters (Table 2). Table 2 is not meant to be all-inclusive, but does provide a usable reference list and an indication of the variety of prescriptions for which documentation exists. Additionally, Martin et al. (1979) summarize available references for both wild and prescribed fire impacts on fuels, citing prescription parameters where available. Even so, considering the total volume of prescription fire literature, relatively few studies document fire prescriptions, fire weather, fire behavior, and effects under one cover. Notable exceptions include Miller's (1977) study of *Vaccinium* response to differential prescribed fires and DeByle's (1981) summary of research burns in western Montana.

The prescriptions specified in the listed studies show general agreement in terms of the factors considered, usually including air temperature, relative humidity, fuel moistures, wind speeds and directions, and various fire danger rating indices, even though prescription variable ranges may vary according to regional differences, site factors, and management objectives. Most recently, studies have suggested that the prescription should focus on those factors most likely to influence the desired fire behavior and effects. Thus, Countryman and Dean (1979) provide guidelines for measuring live fuel moistures in southern California chaparral, stressing that other fuel and environmental variables may be important for prescription fire planning. Sandberg (1980) states that the NFDRS estimate for 1000-hr timelag fuel moisture and surface fire duration are most important for predicting duff reduction and mineral soil exposure in Douglas-fir stands in Oregon and Washington. Finally, Sackett (1980) focuses on surface and ground needle moisture content to explain the reduction of surface and doghair fuels in Arizona ponderosa pine stands. These studies illustrate the importance of tailoring every fire prescription to the unique site factors, the fuels that will carry the fire, and the management objectives for an area.

Table 2. Representative studies of prescription fire by vegetation type or geographic region

Author	Scope of study
Green (1981)	Southern California chaparral
Sackett (1980)	Southwestern ponderosa pine
Wright (1980)	Semi-desert, grass-shrub types in the Southwest
Sandberg (1980)	Douglas-fir understory in the Pacific Northwest
Wright and Bailey (1978)	Grasslands of the Great Plains
Bruner and Klebenow (1979)	Pinyon-juniper woodlands in Nevada
Wright et al. (1979)	Sagebrush-grass and pinyon-juniper communities in the Intermountain Region
Mobley et al. (1978)	Southern forests
Agee et al. (1978)	Mixed conifer forests of the central Sierra Nevada
Martin and Dell (1978)	Plant communities in the Inland Northwest
Norum (1977), Beaufait et al. (1977)	Western larch-Douglas-fir forests in the northern Rocky Mountains
Donoghue and Johnson (1975)	Forests in the northcentral U.S.
Van Wagtendonk (1975)	Mixed conifer forests in Yosemite National Park
Sackett (1975)	Pine stands in southeastern coastal plains
Biswell et al. (1973)	Ponderosa pine in central Arizona
Sando and Dobbs (1970)	Forests in Manitoba and Saskatchewan

Prescription Fire Management and Planning: Research Needs

Prescription fire technologies have been developed and are currently utilized in a variety of vegetation types nationwide. There are still certain vegetation types for which prescriptions have not been specified, as noted in Martin et al. (1979), including lodgepole pine, aspen,

spruce-fir, and subalpine communities in the Rocky Mountains. A basic understanding of fire parameters that produce the desired fire effects will be essential to the development of prescriptions in these types. Further, there is a need for specific decision-making guidelines that will facilitate safe burning operations and achieve management objectives in all vegetation types.

There are other research needs, such as studies of fuel dynamics on wildlands, that should enable managers to improve the specification of critical prescription fire parameters to achieve desired effects. There are also research needs that can only be fulfilled by enlisting the expertise of other disciplines. For example, the potential for management fires to exceed prescription and become wildfires should be addressed jointly by fire management and atmospheric science researchers.

FIRE'S SOCIAL IMPACTS

Impacts on Individuals

The importance of fire's physical impacts transcends its role in altering natural systems. Taken in the aggregate, fire-induced physical changes also produce social impacts, that is, upon the individuals and publics who value the market and amenity products from wildland ecosystems. Still, little research has been conducted on fire's impact on human systems, particularly the social and economic impacts of fire in wildlands.

Public acceptance of prescription fire has lagged behind agency implementation of progressive fire management programs for a variety of reasons: 1) Overgeneralized interpretation of the Smokey Bear message; 2) Potential conflicts with air quality guidelines in both rural and urban settings; 3) Lack of consensus among resource professionals regarding fire use (Glascock 1972). Further Tiedemann (1981) notes that fire's effects on individuals are difficult to quantify and assess because human attitudes are involved.

There is little published information on fire's impacts on visual perceptions, even though methods do exist for assessing individual preferences for natural and manipulated landscapes. Several authors, including Daniel and Boster (1976), Simpson et al. (1976), Gardner and Melhorn (1979), and Daniel et al. (1979) indicate that schemes exist for assessing user preferences for various scenic settings, perceived management practices, and amenity resources. Even though wildland fires produce a variety of scenic and aesthetic impacts, little documentation exists. McClelland (1977) reports that both lightning and wildfires are instrumental in stimulating the diversity in natural vegetation so essential for aesthetic resources in Glacier National Park, although few data are presented. Still it is conceivable that prescription fires could be assessed according to existing landscape methods. Such an effort would require that the physical impacts of prescription fire be adequately described in verbal or visual terms and that survey instruments be developed to objectively assess user perceptions of these physical changes.

Several researchers have focused on the psychological perceptions of wildland users in relation to fires. Folkman (1975, 1976, 1977) surveyed the knowledge levels, attitudes, and behaviors of wildland users, particularly as related to their contributions to forest fire risk. He reported that the propensity of wildland users toward risky behavior is only weakly associated with their knowledge levels and atittudes about fire. Hogans (1979) questioned users about fire danger in dispersed settings, finding general awareness of fire danger and agreement with fire prevention measures (except total closure) by fire officials. Stankey (1976, 1980) and Rauw (1980) examined wilderness users' knowledge and attitudes toward natural fires allowed to run their course. They indicate a general recognition that prescribed fires may be of benefit to some forests, but reveal a bias toward continued fire exclusion that can be remedied through education programs.

Impacts on Society

In a free-market society, individuals express product preferences through expenditures, and policy preferences through the electoral, legislative, and judicial processes. Thus, society's expenditures and fire management policies should reflect the aggregate preferences of individuals for fire management outputs. Lee (1977) has suggested that the analysis of societal preferences for fire and fuel management is confounded by institutionalized views that fire is a threat, rather than an ecological force. Even so, several researchers have attempted to examine the benefits and costs of wildland fire management programs. Bonnicksen and Lee (1979) present a systems model for analyzing the persistence of an unsuccessful wildfire exclusion policy in southern California. They found that increased expenditures over time have not appeared to reduce damages nor area burned in the Cleveland National Forest. Similar conclusions have been reached by Omi (1977) for the Angeles National Forest and Gale (1977) for the national forest system as a whole.

Economic analyses of prescribed burning are confounded by the lack of reliable data relating inputs to outputs. Zivnuska (1968) analyzed the costs of prescribed burning and concluded that, even with the data problems, the overhead and indirect costs (plus those associated with undesirable effects) may outweigh the direct costs of burning. Gale (1977) found that resource values are neither properly assessed nor correctly used by fire management planners.

Mills' (1979) simulator for the economic evaluation of fire management activities represents a first attempt to develop a framework for analyzing fire management activities in terms of benefit-cost trade-offs with other expenditures at the regional or national level. Widespread acceptance of prescribed burning as a viable land management practice will not become a reality until its

economic efficiency can likewise be established on a site- or area-specific basis.

Fire's Social Impacts: Research Needs

In summary, fire's social and economic impacts have been previously analyzed in terms of individual and societal preferences, but large gaps still exist in our knowledge of prescribed fire's social impacts. Research areas of importance include:

1. Relationships between user perceptions and prescription fire impacts on wildlands, including areas adjacent to human developments;
2. Studies of prescription fire cost-effectiveness, including schemes that balance both short- and long-term benefits and costs from burning; and
3. Studies of the relationships between fire as an ecological process, fire as a social process, and the formulation of public policy with respect to prescription fire.

Experimental controls in social and economic studies are especially difficult, particularly in studies involving individual or public attitudes. In such studies, correlations between measured variables may be calculated, but cause-effect relationships are difficult to verify. Nevertheless, we attach a high priority to studies relating fire as an ecological process to the formulation of public policy with respect to prescription fire. Our rationale is based on the recognition that public attitudes may ultimately be of greater importance to the acceptance or rejection of prescription fire practices than biophysical effects within an ecosystem.

SUMMARY AND CONCLUSIONS

There are many potential uses of fire on recreational wildlands, but widespread implementation of prescription fire programs is hindered by uncertainties concerning fire's impacts on both the physical and psychological settings afforded to individuals and society as a whole. These uncertainties lead to inevitable conflicts over the implementation of progressive fire management programs, but future research can and should aid in reducing these conflicts.

Prescription fire differs from wildfire because of the managerial controls exerted over the fuels, weather, and topographic influences on fire behavior and fire effects. Ideally, selection of the appropriate fire prescription results in a fire that burns on the manager's terms — not according to the extreme conditions that produce wildfires. Used in this fashion, fire can be an efficient tool to achieve a variety of land management objectives. Unfortunately, there are large gaps in our knowledge of prescription fire's physical and psychological impacts.

Our literature assessment has indicated that the existing knowledge of fire's physical effects is disjoint, often non-quantitative, and commonly results from studies that lack experimental control over important independent variables. These shortcomings render studies incomparable, even for the same vegetation type. The existing literature inhibits the development of ecologically meaningful generalities and predictions because:

1. Many studies have focused on wildfire, instead of prescription fire effects;
2. Documentation of individual fire characteristics, i.e. intensity and duration, is generally poor, and sometimes not linked to a stated prescription;
3. Replications of previous experiments are generally lacking, in part due to poor documentation;
4. Short-term studies of effects from a single fire offer a limited perspective on the range of potential outcomes within a dynamic system;
5. In the absence of synthesis efforts, the classical approaches to studying fire effects are inadequate for assessing the mechanisms underlying fire as an ecological process.

The resulting tendency toward analyzing fire effects according to separate subsystems, e.g., flora, fauna, soils, etc., de-emphasizes important interactions and is also inadequate for analyzing human perceptions about fire. Moreover, studies are needed concerning prescription fire impacts on individuals and user-publics, including those who do not directly use wildlands for recreation, yet are affected by fire's social and political consequences.

Priority Research Themes (refer to appropriate section of the foregoing text for additional details)

We conclude this paper by reiterating general priority themes for future prescription fire research. In keeping with our stated intent, this assessment is of specific relevance to the Rocky Mountains and adjacent High Plains that constitute the geographic interests of the Eisenhower Consortium for Western Environmental Forestry Research. However, we hope that researchers elsewhere will find this assessment useful in defining their own future research efforts.

(a) The role of fire in community dynamics
(b) Individual plant responses to fire: tree mortality
(c) Fire history
(d) Quantification of the relationship between fire intensity and soil heating
(e) Relationships between fire as an ecological process and public policy formulation with respect to prescribed fire.

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ABSTRACT

The existing literature on wildland fire is assessed in terms of both the biological and social impacts of prescription fire on recreational wildlands. Gaps in the literature are noted and future areas of needed research are suggested, with particular emphasis on the Rocky Mountains and adjacent High Plains.

Key Words: prescription fire, fire behavior, fire effects, recreational wildlands